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FINAL REPORT ON CONTRACT NAS8-31170

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The Study of Efficient Low-Power Diffraction Designs

Submitted To

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George C. Marshall Space Flight Center

Marshall Space Flight Center, AL

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INTRODUCTION

This contract covered work on a number of instrument systems for radiation detection and measurement for use in the laboratory, at accelerators, and on balloon and satellite platforms. These are treated separately as follows:

1. Nuclear Radiation Monitor (NRM)

   A laboratory study was made of an anticoincidence system.

2. Design and Fabrication of Parallel Plate Ion Chambers for Measurement of Ionization Loss by Relativistic Heavy Ions.

3. Design and Calibration of Ionization Chambers and Proportional Counters for the Active Radiation Detector (ARD) on Spacelab-1.

1. THE NUCLEAR RADIATION MONITOR

Introduction

An important experimental restriction of sensitivity for satellite-borne x-ray spectrometers is the induced radioactive background. Since this radiation is largely nuclear γ's, the confusion with similar radiation from cosmic sources of interest is evident. The nuclear radiation monitor (NRM) is planned to be flown on Shuttle as part of the Spacelab 2 payload (see Figures 1 and 2) in order to perform detailed measurements of the radiation environment in the payload bay. An early quantitative assessment of this background will be invaluable for the many high energy astronomy experiments planned for Shuttle flight.

The detector head was designed and fabricated at UAH and delivered to MSFC for assembly and integration with the flight electronics and phototubes. It has subsequently passed all qualifications and acceptance tests and has been integrated onto the Spacelab-2 pallet at KSC (see Figure 8).

TECHNICAL APPROACH

A description of the instrument was given by Fishman in the Proceedings of the Symposium on Gamma-Ray Spectroscopy, NASA, GSFC, 1978.

The main detector is a 5" x 5" diameter sodium iodide, NaI(Tl), scintillation crystal viewed by a 5-inch photomultiplier tube. The NaI(Tl) detector should be capable of identifying many of the stronger, separated gamma-ray lines with an expected energy resolution of 8% FWHM at 662 keV. The detector will operate in an energy range from 0.1 to 20 MeV. A charged-particle anticoincidence shield, consisting of a 1 cm-thick plastic scintillator viewed by three 2-inch photomultiplier tubes, covers the crystal detector. The entire detector is designed to have nearly omnidirectional response.

Under the scope of work covered in this report a laboratory study was made of the anticoincidence plastic shield. A laboratory model, see figures 3 and 4, was constructed consisting of a 5 x 5 inch NaI(Tl) crystal mounted crystal-up in a cylindrical stand, surrounded by a styrofoam cylinder. This cylinder contains the plastic shield which is viewed from the bottom in this model by 3 two-inch photomultiplier tubes. The shield will surround the crystal on all sides except that covered by the 5 inch photomultiplier tube. For the purpose of testing, pieces of plastic scintillator were placed on top of the crystal (Figure 3), this being the position most-obscured from the p.m. tubes.

The natural background was then used to test the system. Mu-mesons of energy > 1.5 MeV were selected by placing a coincidence requirement between the outputs of the 3 two-inch tubes (summed) and the 5 inch crystal. The discriminator on the latter was set at 1.5 MeV. The spectrum of these selected particles in a 0.5 inch slab of NE 102 plastic is shown in Figure 5. A reference spectrum of Cs-137 in the central crystal is shown in Figure 6. As may be seen, fast singly-charged particles could readily be discriminated from noise. A thinner (0.125 inch) piece of plastic scintillator proved insufficient however to achieve this.

The electronic system is shown in Figure 7. Spectra will be accumulated in at least two formats under the control of a microprocessor.

SPACELAB 2 PAYLOAD CONFIGURATION

JOHN GENTER
JANUARY 1978

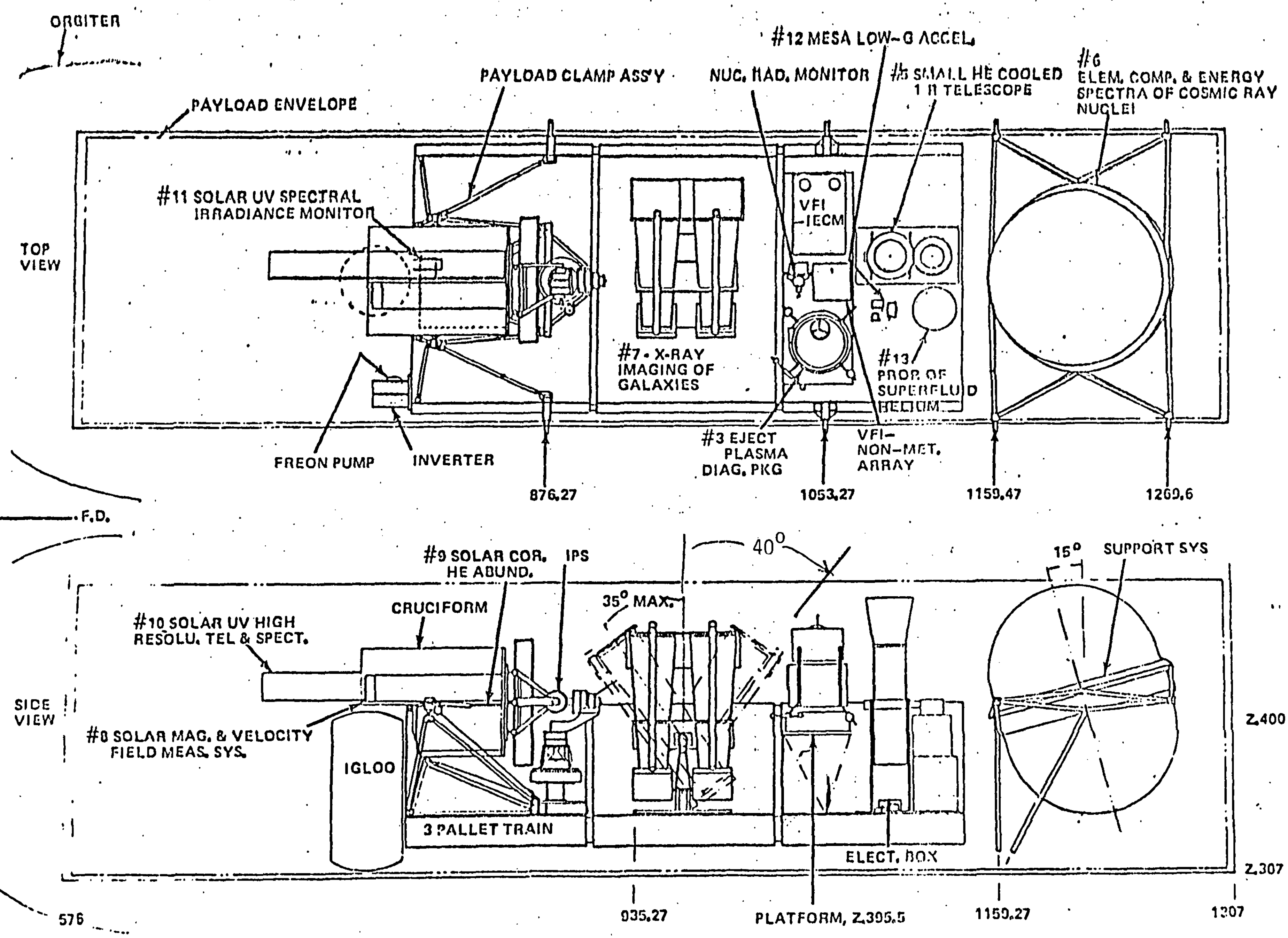
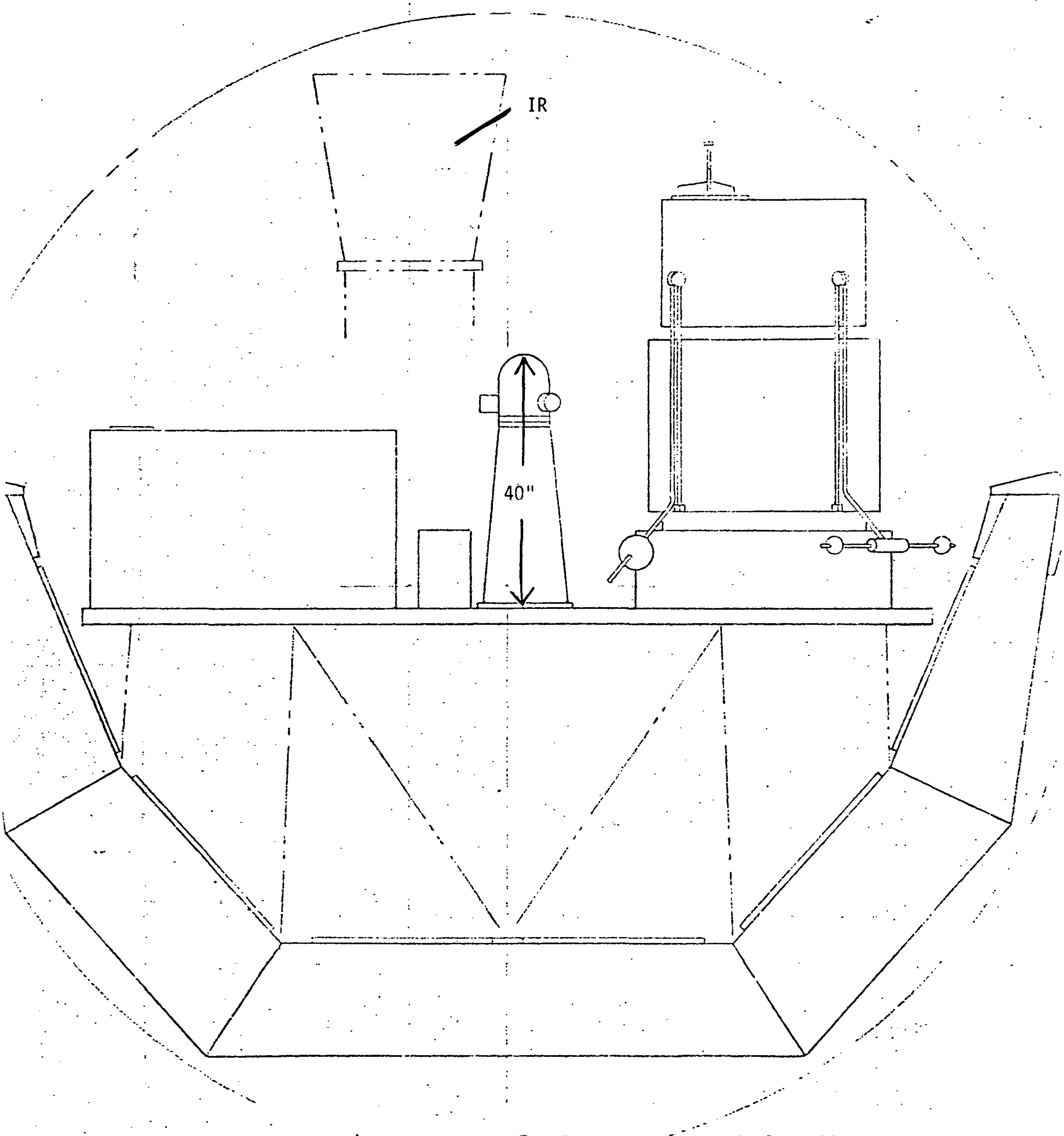


FIGURE 1

VIEW B-B



VIEW C-C

Scale 1:20

FIGURE 2

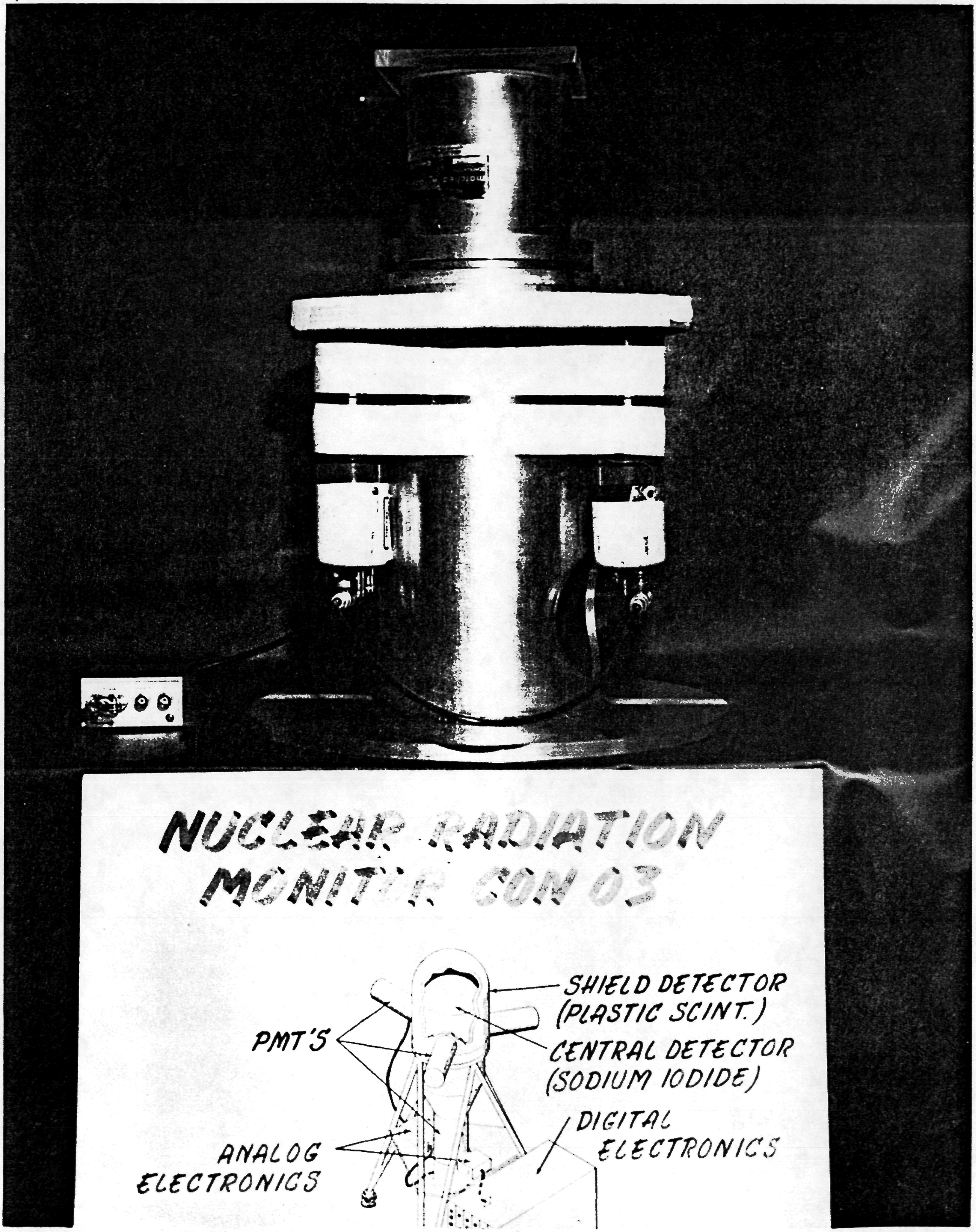

NUCLEAR RADIATION
MONITOR CON 03
SHIELD DETECTOR
(PLASTIC SCINT.)
PMT'S
CENTRAL DETECTOR
(SODIUM IODIDE)
DIGITAL
ELECTRONICS
ANALOG
ELECTRONICS

FIGURE 3

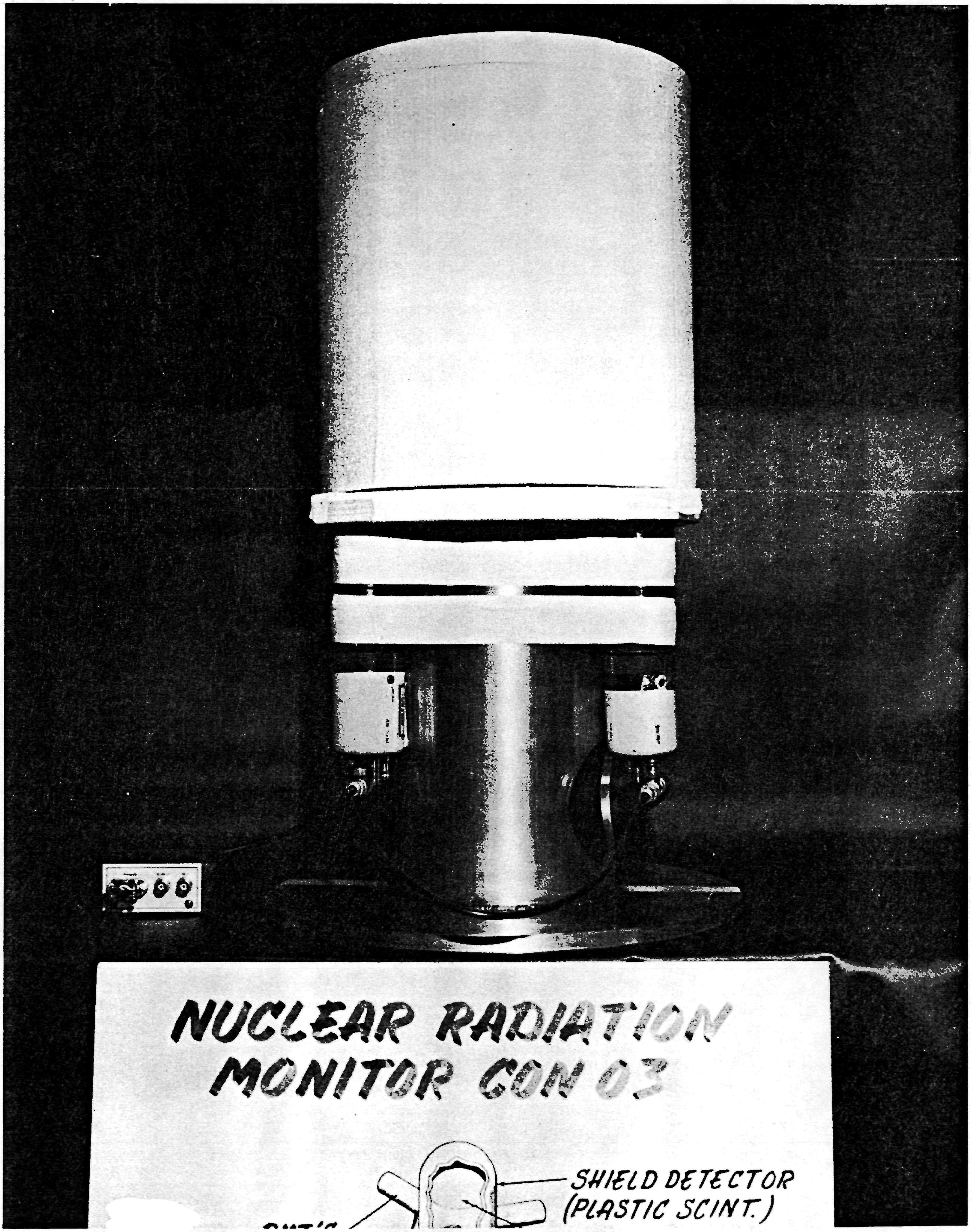

NUCLEAR RADIATION
MONITOR CON 03
SHIELD DETECTOR
(PLASTIC SCINT.)

FIGURE 4

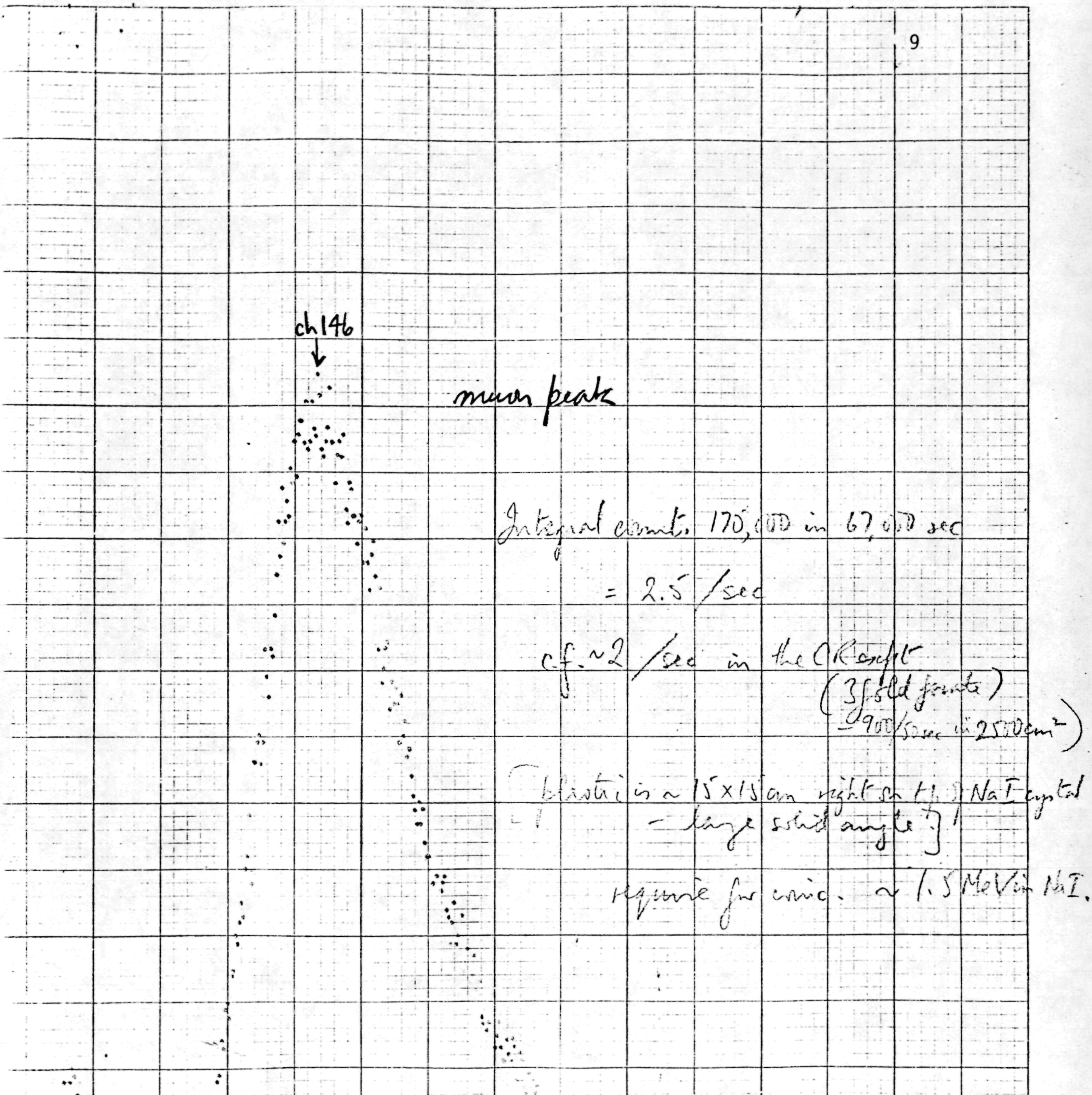

ch146
muon peak
Integral counts 170,000 in 67,000 sec
= 2.5 /sec
c.f. ~2 /sec in the
(3 fold
900/ sec in 2500 cm²)
[plastic is ~ 15 x 15 cm right on the NaI crystal
— large solid angle]
require for coinc. ~ 1.5 MeV in NaI.
72

FIGURE 5

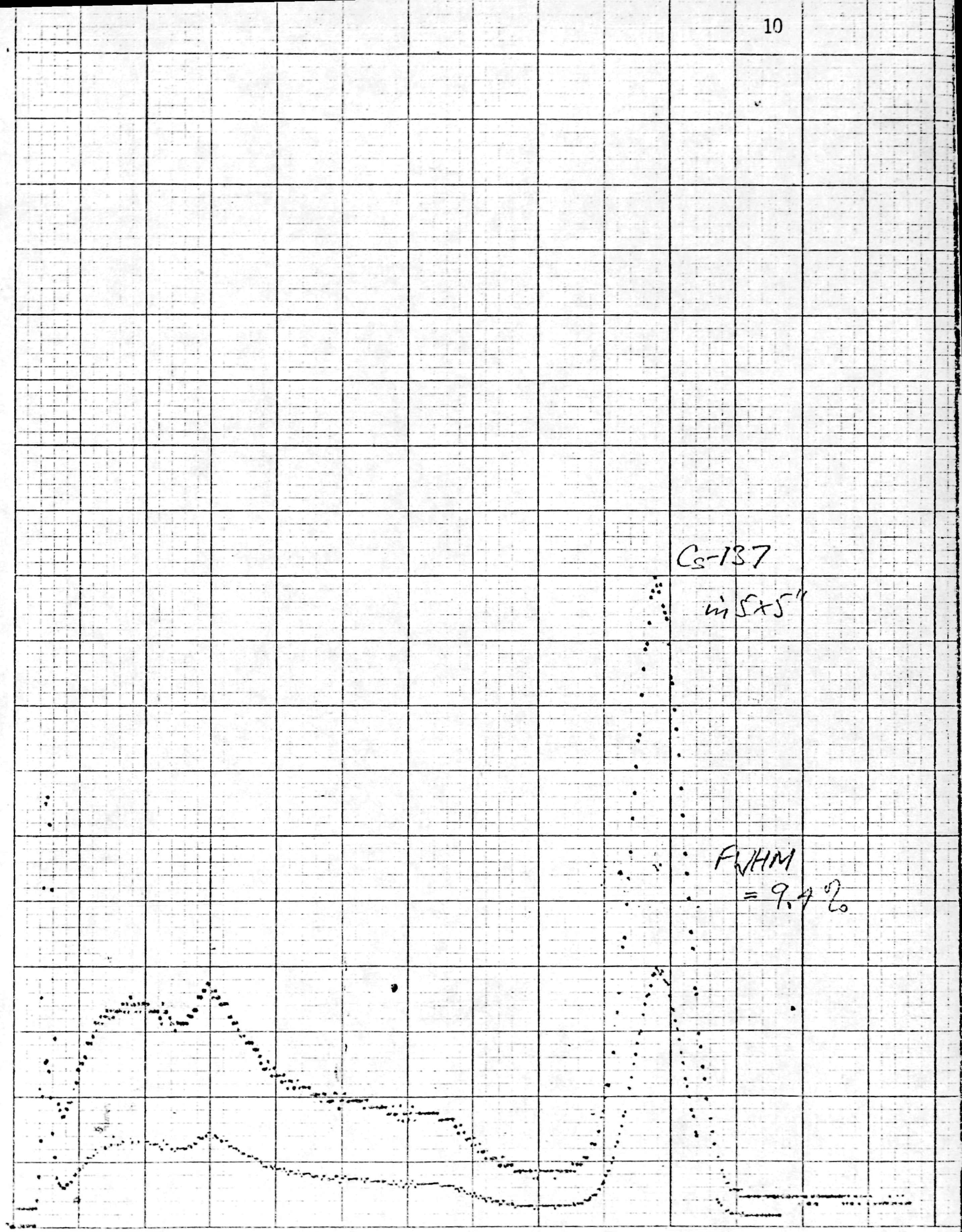


FIGURE 6

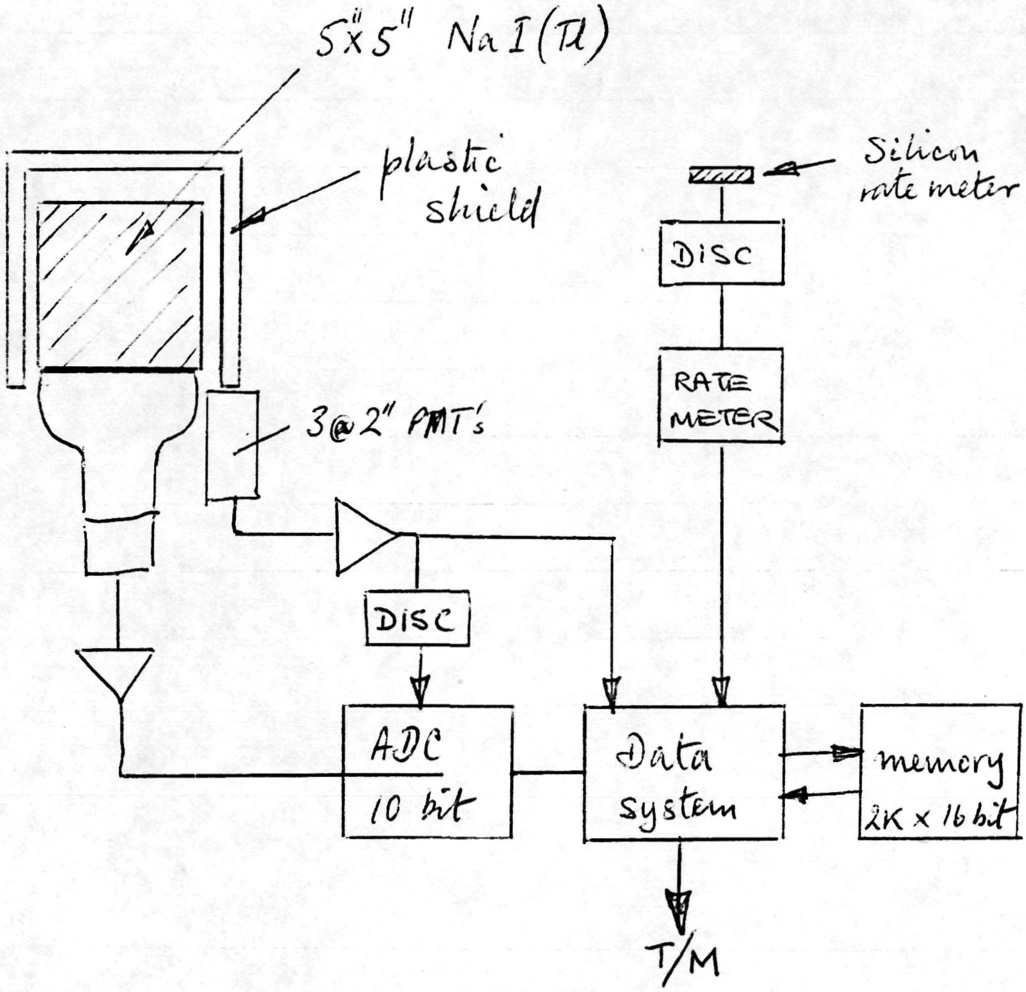


FIGURE 7 NRM - ELECTRONICS BLOCK DIAGRAM

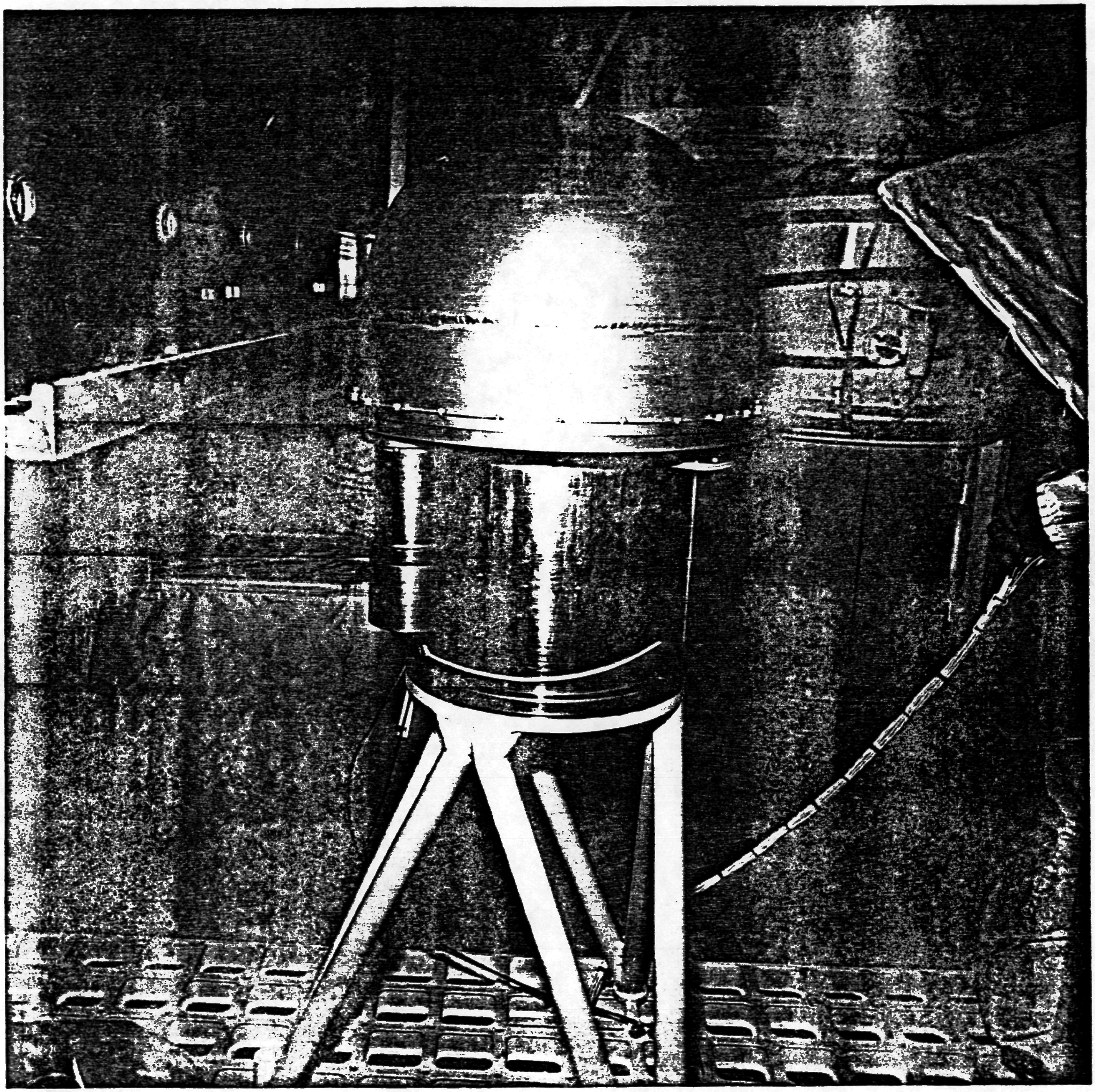


FIGURE 8. THE FLIGHT MODEL OF THE NRM SHOWN DURING MOUNTING TO THE SPACELAB-2 PALLET AT KSC. THE THERMAL SHROUD HAS NOT YET BEEN PLACED ON THE INSTRUMENT. THE LARGE CYLINDER IN THE BACKGROUND IS THE INFRARED TELESCOPE.

2. AN EXPERIMENT TO MEASURE THE ENERGY DEPOSIT OF RELATIVISTIC HEAVY IONS

Abstract

Recent calculations indicate that the energy deposit of relativistic heavy ions exceeds that predicted from a Z^2 dependence at high values of Z. THis effect has not been seen experimentally, because accelerator-produced beams of relativistic particles of $Z > 26$ are just becoming available and the fluxes of such elements in the cosmic rays are too low for accurate measurement of energy deposit distributions. Both these situations are changing.

An experiment is described here, which will measure energy deposit distributions of relativistic heavy nuclei in ion chambers and a Cerenkov detector in order to test the theoretical calculations.

NOTE ADDED (1984)

This experiment was designed in 1977 but never took place as the funds for the accelerator exposure were not available. Subsequent measurements by the HEAO Heavy Nuclei Experiment group using ion chambers at Berkeley rendered this experiment less important and resources were allocated elsewhere.

INTRODUCTION

Measurement of the fluxes of cosmic rays more massive than iron with electronic, plastic or emulsion detectors requires calculation of the ionization deposits of such ions. Eby and Morgan (1972) undertook a calculation for relativistic ultra heavy cosmic rays using exact Mott cross-sections. Their results indicated a significant departure above Z = 20 from the Z^2 dependence classically derived from the Born approximation. Approximate corrections to the Bethe-Bloch formula were derived (Morgan and Eby, 1973). Their results have recently been corroborated by further higher order correction calculations (Ahlen, 1978, but no experimental evidence for the effect has been published due to the paucity of data and poor experimental resolution for the ultra heavy cosmic rays.

EXPERIMENTAL OBJECTIVES

1. Measure divergence from Z^2 dependence of energy deposit in thin dE/dX detectors by heavy ions of charge Z as a function of Z. Compare measurement with calculations of Eby and Morgan. Two ion chambers and one Cerenkov detector provide the principal measurements.

2. Measure development of the energy deposit by energetic δ-rays produced by absorbers of varying thickness placed before the dE/dX detectors and compare with calculations.

3. Measure effect of shield thickness placed between two ion chambers and verify calculations of mass thickness required to render the two measurements independent.

EXPERIMENTAL APPROACH

The proposed experiment is designed to measure the response of ion chambers and Cerenkov counters to relativistic argon and iron atoms. The energy deposited per ion pair is assumed to be independent of projectile Z so that the energy loss corrections should show up in ion chamber response. The energy loss correction is largest for the high energy delta rays, some of which escape the chamber so one must calculate the correction only for the energy deposited in the ion chambers. Monte Carlo calculations indicate that the effect amounts to a few percent in the $Z = 18$ to 25 range and increases as more material is added in front of the ion chamber. Calculations also suggest that a similar effect occurs in Cerenkov counters. This is because a certain fraction of light output in these detectors is due to high energy delta rays produced by the primary ion and this is where the corrections to the usual Z dependence are largest. We do not yet have detailed calculations of the magnitude of this effect, but it is thought to be of the same order as the energy loss correction.

The experiment will consist of measuring the ratio of ion chamber and Cerenkov response for incident relativistic argon and iron atoms and comparing it with theory. This will be done with different absorber thicknesses to measure the dependence of the effect on delta ray buildup. This requires an accuracy of measurement of better than 1%. Despite the statistical spread in energy deposition, we believe this can be done because the peaks of the pulse height distributions can be located to better than 1% accuracy. It will require accurate calibration of the detectors and also very linear response of the

associated electronics. The latter can be verified independently. The ideal situation would be to have both ions available at the same time to eliminate drift in the detectors but this may not be possible. Corrections for any drifts will then be necessary with the help of calibration sources. Corrections to energy deposit distributions must be made for spallation products and energy loss in the copper absorbers and in the exit sections of the accelerator.

Landau fluctuations in energy deposit in two thin ion chambers placed in series in a particle beam may be decoupled by a thin absorber between them. The two dE/dX measurements are then considered to be independent. We plan to check on coupling effects between ion chambers and have thus included a variable absorber between the two chambers.

DESCRIPTION OF THE INSTRUMENT

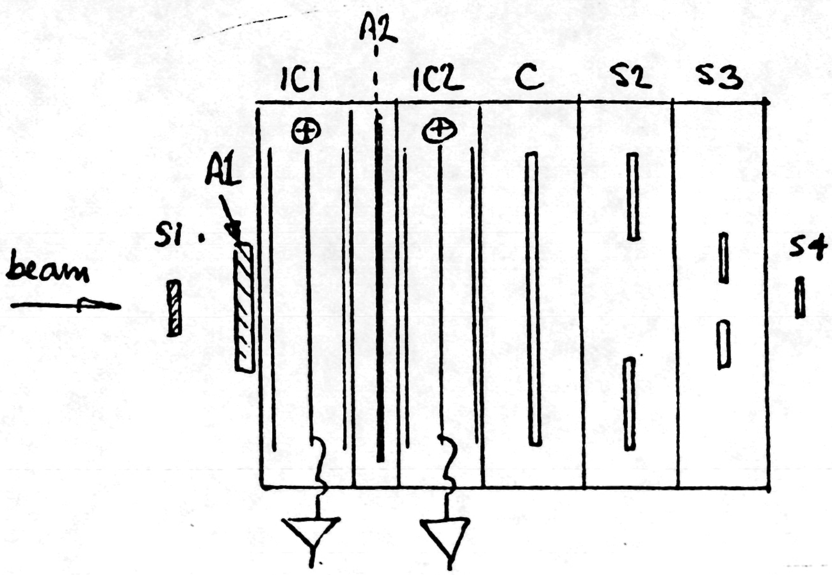


FIGURE 1. Schematic drawing of the arrangement of light-boxes, absorbers and ion chambers in the accelerator beam. The key to symbols is given in the text. Particles move from left to right.

The experimental system has cylindrical symmetry and is housed in a box as shown in Figure 1. It contains 5 light boxes, including 1 Cerenkov radiator (C) and 4 scintillators (SI-4), two ion chambers (IC1,2) and 2 variable absorbers (A1,2). The arrangement is shown in Figure 2.

S1 and S4 are 2" diameter, 1/4" thick plastic scintillators used for alignment with the beam. After alignment S1 is demountable.

A1 is comprised of 6 discs, 5" in diameter, mounted on a wheel. Discs are copper and up to 2 cm thick.

The ion chambers are identical, 8 cm total gap width each, active diameter 26 cm filled with 90% Ar/10% CH_4 (flow through), and with all electrodes (3 each) and windows (2 each) made of gold-plated Kapton film of thickness 0.25 mil (6 μm). A section of an ion chamber is shown in Figure 3.

The Cerenkov radiator is a 12 inch diameter 0.25 inch thick disc of UV transmitting lucite and may be exchanged for teflon, glass and other material. The light is viewed with 4 x 3" photomultiplying tubes.

S2 and S3 are annuli of 0.25 inch thick plastic scintillator with the following dimensions:

S2 : ID 6" OD 12"

S3 : ID 2" OD 6"

Each is viewed with 2 x 3" tubes.

ELECTRONICS

Outputs of 1C1 and 2 and $\hat{C}$ only are digitized. Coincidence between $\hat{C}$ and S4 (or perhaps S3 or S4 but not both) will provide the

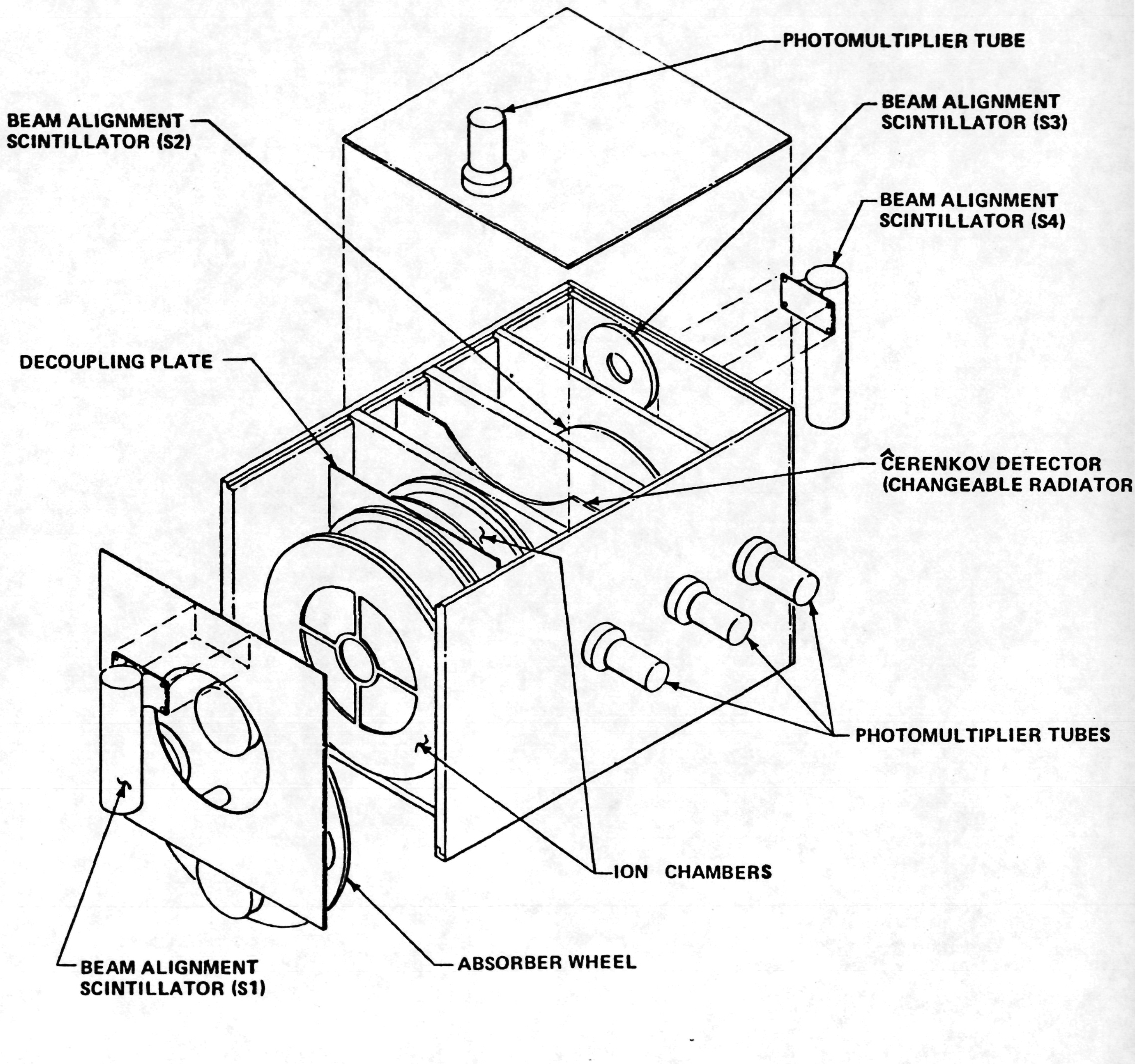


FIGURE 2.

BERKELEY EXPERIMENT INSTRUMENT

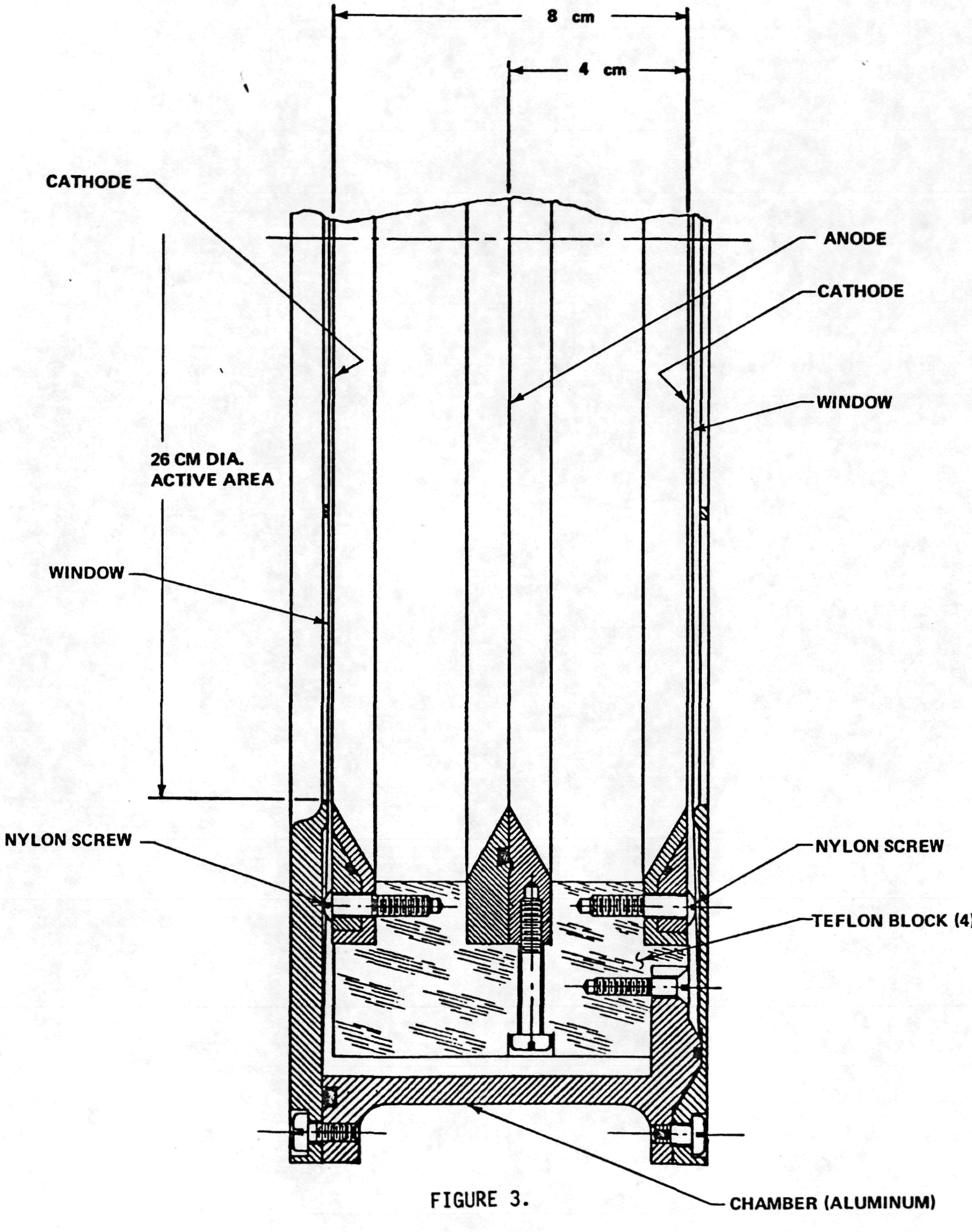


FIGURE 3.

ION CHAMBER
(BERKELEY EXPERIMENT)

FIGURES 4 and 5

Photographs of one of the ion chambers. The electrode assembly is separated from the housing in Figure 4. In both figures the gold-plated Kapton film windows are removed.

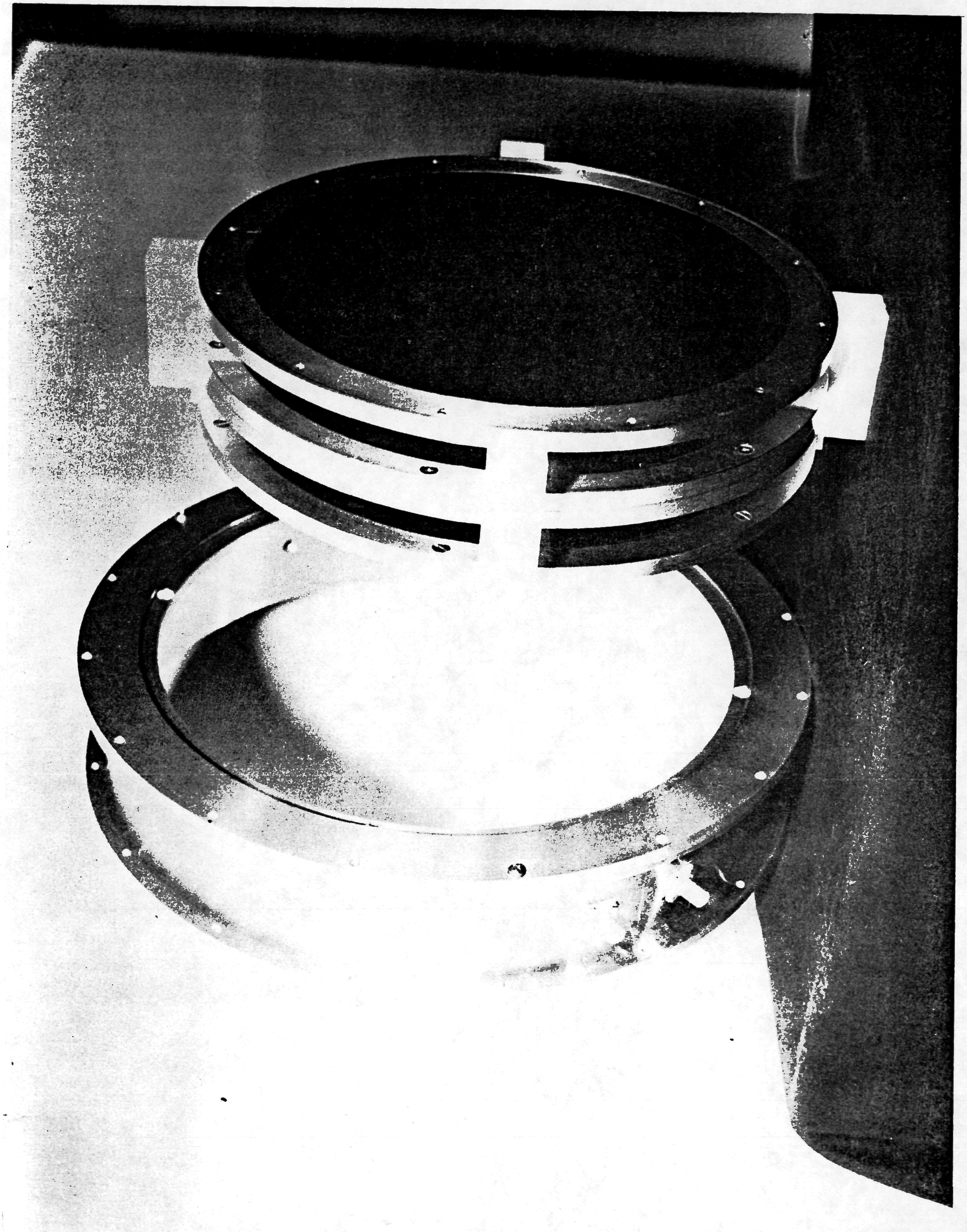


FIGURE 4

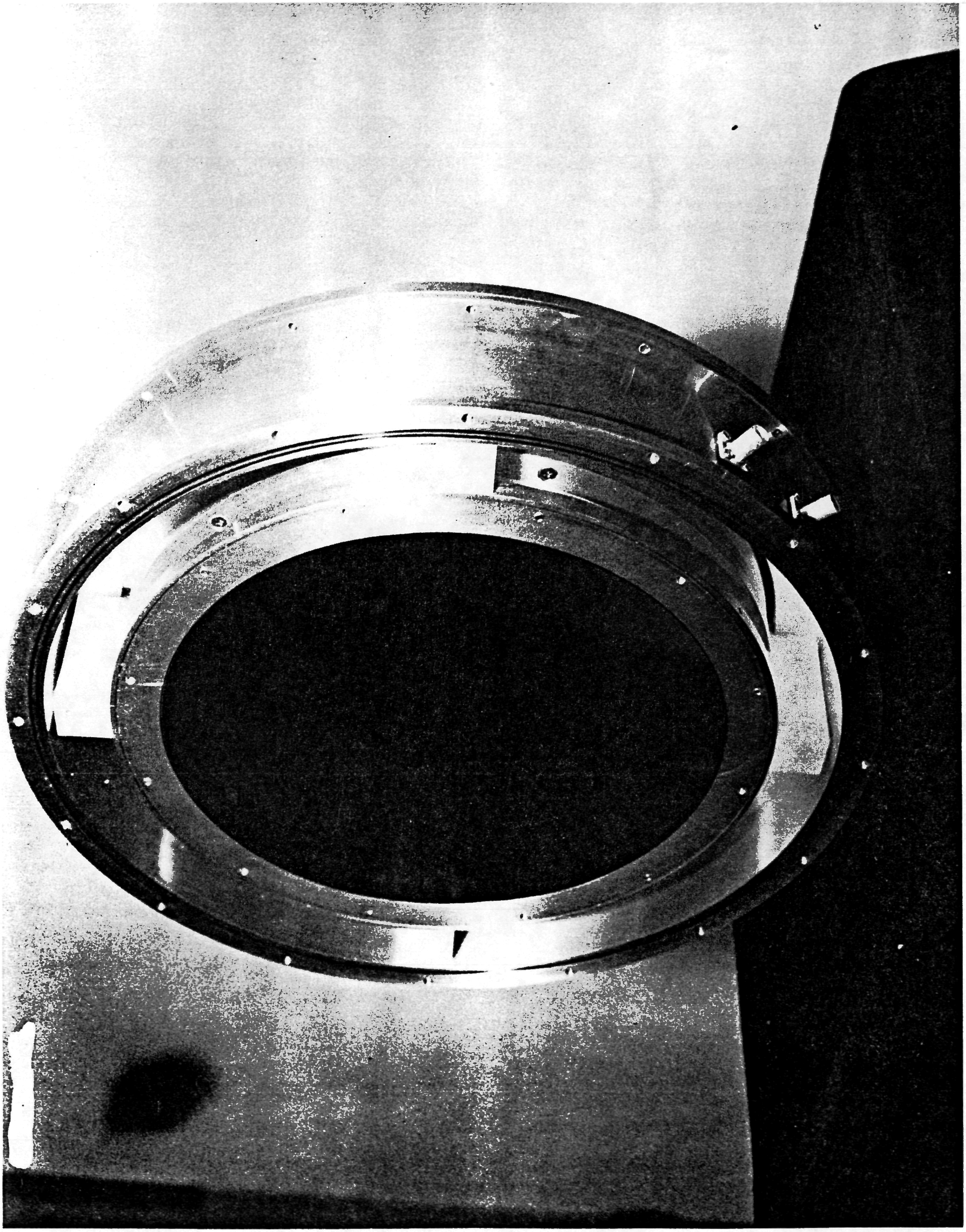


FIGURE 5

acceptance criteria. Signals above discriminator levels in S2 and perhaps S3 will provide means of rejecting off axis particles or nuclear interactions.

Data acquisition will be by CAMAC equipment and a PDP-11 computer for which the software has been developed under this contract.

The instrument was delivered to NASA/MSFC in 1978.

REFERENCES

1. S. H. Morgan and P. B. Eby, Nuclear Instruments and Methods 106, 429, (1973).

2. P. B. Eby and S. H. Morgan, Phys. Rev. A, 5, 2536 (1972).

3. S. P. Ahlen, Phys. Rev. A, 17:3, 1236, (1978).

3. THE ACTIVE RADIATION DOSIMETER FOR SPACELAB-1

INTRODUCTION

The ARD was designed to provide a differential measurement of radiation dose and particle count rate in orbit inside the Spacelab-1. Under this contract we defined and selected ion-chambers for the dose measurement and proportional counters for particle counting. Definition and consultation was provided to MSFC during the design and fabrication of the pulse counting logic and interface electronics as well as the mechanical design of the container, mounting hardware and materials review requirements. Complete drawings and specifications are available as part of the NASA VFI program documentation and are not repeated here.

A prototype ion chamber was purchased from Digital Data Dosimetry of Tulsa, Oklahoma and subjected to rigorous laboratory testing and calibration. As a result of this, the sensitivity of the instrument was reduced from 1 μrad per count to 5 to 10 μrad per count (adjustable). Three units were purchased, two of which became flight units and one backup unit. All were repeatedly calibrated before the flight.

Proportional counters were selected and purchased from Reuter-Stokes Company, and the thresholds adjusted and set to measure minimum-ionizing singly-charged particles transiting the active volume.

Two complete instruments were installed in racks in Spacelab-1 and performed without fault. They were satisfactorily re-calibrated at MSFC after return. Data analysis is presently underway.

ION CHAMBER DOSIMETERS

The tissue-equivalent ion chamber dosimeters (IC's) are designed* to make differential measurement of absorbed dose in a mixed radiation field typical of Spacelab orbits. Each dosimeter consists of a gas-filled ion chamber, electrometer sensor, and pulse generator. When each preset unit of radiation (measured in tissue-rads) is accumulated, a pulse is sent to advance an internal register and reset the electrometer integrator. Preset dose units are in the range of 5 to 10 μ rads per pulse and expected count rates in orbit vary from a low value of a few counts per hour to a few counts per second in the South Atlantic anomaly.

The calibration procedure is designed to measure the sensitivity of the instrument in μ rads per count, and to check the linearity of the system over the expected dose rate range of up to several hundred μ rads per hour.

A view of the ion chamber assembly is shown in Figure 1.

* TEIC I/El, Digital Data Dosimetry, Tulsa, Oklahoma.

CALIBRATION

Dose Calculation

$$\text{Energy absorbed per gm} = \frac{\mu}{\rho} \cdot F \qquad \text{ergs g}^{-1}$$

$$= \frac{\mu}{\rho} \cdot \frac{F}{100} \qquad \text{rads} \qquad (1)$$

where μ/ρ is the energy transfer coefficient (for tables, see Hubbell and Berger, 1965), and

F , the energy flux in ergs cm^{-2},

$$= \frac{3.7 \times 10^{10} \times \text{source strength in Ci} \times E_\gamma \times 1.6 \times 10^{-12} \text{ ergs cm}^{-2}}{4\pi r^2} \qquad (2)$$

where E_γ is the proton energy in eV

and r is the source-absorber separation in cm.

Some measured and calculated dose rates of interest are shown in Table 1.

TABLE 1

Some dose rates of interest:

Typical sea level background in US:	∿ 10 μ rad $hour^{-1}$
10 μ Ci Cs-137 @ 30 cm:	37 μ rad $hour^{-1}$
10 μ Ci Cs-137 @ 5 cm:	1.3 m rad $hour^{-1}$
100 m Ci Cs-137 @ 50 cm:	130 m rad $hour^{-1}$
South Atlantic anomaly peak:	∿ 100 m rad $hour^{-1}$

Experimental Arrangement

The setup used in shown in Figure 2. Both source and detector are at a fixed distance ($\sim$ 1 m) from the floor. The source position was unchanged but the detector and shield were on a movable trolley. The source used was a nominal 100 m Ci of Cs-137 (New England Nuclear NER 401 H, serial number CS-315) of actual activity 93.8 ± 5 m Ci on August 8, 1975. At the time of this calibration, its activity was 79.2 m Ci.

The ARD was placed in the γ-field so that the IC and both PC's were equidistant, d meters, from the source. The number of counts per unit time for each detector was recorded. For the PC's the mean of 17 measurements of counts per second was taken in each case. For the ion chamber, the counting interval was varied depending on the count rate so that the uncertainty in counting was less than 3%. At count rate > 50 per 100 s a counting period of 100 s is adequate. At lower count rates longer interval were used, and at very low rates of a few per 100 s or less, the measurement was made of the intervals between actual counts. This is conveniently done with the GSE since the count register of the ARD is read out and displayed every second by the GSE.

These results for the ion chambers are shown in Figure 3 and 4 for ARDS's 1 and 2 respectively. Plots of PC count rate versus dose rate are shown in Figures 5, 6 and 7.

From this data and equation (2) the sensitivities of the ICs were determined to be:

ARD No. 1 ----- 6.1 ± 0.3 μ rads $(ct)^{-1}$

ARD No. 2 ----- 10.4 ± 0.5 μ rads $(ct)^{-1}$

The IC's are seen to be linear over the range 300 μ rads $hour^{-1}$ to 100 m rads $hour^{-1}$ are probably linear up to an order of magnitude higher in dose rate.

PROPORTIONAL COUNTER RATE METERS (PC'S)

These counters are xenon-filled stainless steel cylinders with aluminum liners (Reuter-Strokes #RS-P3-0803-287). Shown in Figure 8, they are 4 inch long and 1 inch in diameter. There are two PC's in each ARD, one being covered with a copper sleeve 1.27 mm thick for partial discrimination between protons and soft electrons.

Any charged particle intersecting a PC or any photon interacting within a PC will advance the ratemeter for that counter, provided sufficient energy is deposited in the counter to exceed the preset threshold discriminator. For a given radiation field the count rate varies with the system gain and noise and with the discriminator level. This level was set above system noise but low enough to be exceeded by most minimum ionizing singly-charged particles.

Energy Loss Calculation and Discriminator Level Justification

Mean ionization loss for relativistic $z = 1$ particle in Xe = 7.5 keV cm^{-1}.

Mean ionization loss across a diameter of the PC = 19.5 keV.

With discriminators set at 8.9 keV, > 90% of all particle trajectories intersecting the PC will exceed this level. Since some particles deposit less than the mean, an overall efficiency of 85% is estimated for relativistic particles. Efficiency is greater for slower particles of sufficient energy.

Consistency of PC Background Count rate with Other Measurements

An experimental measurement of the fast muon flux at Huntsville using the MSFC-UAH cosmic ray instrument gave approximately 0.012 $(cm^2\ sr)^{-1}$. For the effective area of these PC's of 18 cm^2 we should expect a fast muon rate of about 0.4 s^{-1}. Actual measured background count rates with the ARD PC's were in the range 0.6 to 1.5 s^{-1}. Since this includes all background radiation, the AC measurement is in agreement with prediction.

The energy deposit calibration of the PCs was made using low energy photon sources of 5.9 keV (Fe-55) and 14.4 keV (Co-57). The excellent resolution and noise figure of these counters is shown in Figure 9.

Count rates of the PC's in a calibrated γ-field were recorded during the calibration of the ion chambers by the shadow-shield method described below. Plots of count rate versus dose as measured by the ion chambers are shown in Figures 5, 6 and 7.

The proportional counters are not quite linear with dose rate as shown in the figures. In the event of IC failure, however, they will give a reasonable estimate of dose rate. The presence on PC No. 2 of the 1.27 mm thick copper shield did not affect the counting rate greatly compared to PC

No. 1 for 0.66 MeV γ-rays. It will, however, affect the count rate for low energy electrons.

Transfer Calibration and Check Source

During the period between calibration and flight, (approximately one year), checks must be made of the ion chamber (a) to see if it is operating and (b) to check the constancy of the sensitivity (μ rads ct^{-1}).

This is effected with a small source placed on a marked spot on the aluminum case of the ARD. The source strength is 10 μ Ci and the effective separation of source and detector is 5 cm. The dose rate is 1.3 m rad $hour^{-1}$, approximately two orders of magnitude above laboratory background and two orders below orbital maximum rate (see Table 1). Baseline data using the transfer calibration source and background measurements are given for ARD's No. 1 and 2 in Tables 2 and 3 respectively.

TABLE 2

TRANSFER CALIBRATION/CHECK SOURCE MEASUREMENTS

ARD No. 1

DATE (1982-1983)	PC 1	PC 2	IC time for 1 count (sec)
	counts/sec (mean of 17 measurements)		
Source on IC Spot			
December 29	7.7	19.4	16.5
29	8.1	20.2	16.0
30	9.2	19.4	16.2
30	9.4	17.6	15.8
January 2	8.9	17.0	16.1
2	7.6	21.0	16.2
2	7.8	17.9	15.9
2	8.5	18.7	16.1
5 (post shake)	9.0	21.2	14.7
5	8.8	19.6	14.7
5	10.2	20.0	14.9
Source on PC Spot			
December 29	108	107	----
30	105	109	----
Room Background			
December 29	1.53	1.12	1100
29	1.59	1.06	
30	1.06	0.94	

TABLE 3

TRANSFER CALIBRATION/CHECK SOURCE MEASUREMENTS

ARD No. 2

DATE (1982-1983)	PC 1	PC 2	IC time for 1 count (sec)
	counts/sec (mean of 17 measurements)		
Source on IC Spot			
December 29	7.7	17.7	----
29	8.1	17.3	----
30	8.8	18.5	----
30	8.5	18.7	----
30	9.5	17.5	----
January 2	8.0	16.6	----
2	8.1	17.1	----
2	8.1	18.3	----
2	7.3	19.4	----
8 (reconstituted post shake)	9.5	19.4	26.5
	10.2	17.6	28.2
	8.6	18.8	28.3
	9.7	19.8	28.2
Source on PC Spot			
December 29	109	104	----
	111	100	----
January 8	96	114	----
Background			
December 29 (in rad. fac.)	0.7	0.6	1500
	0.9	0.4	
January 8 (in SSL)	2.2	1.2	

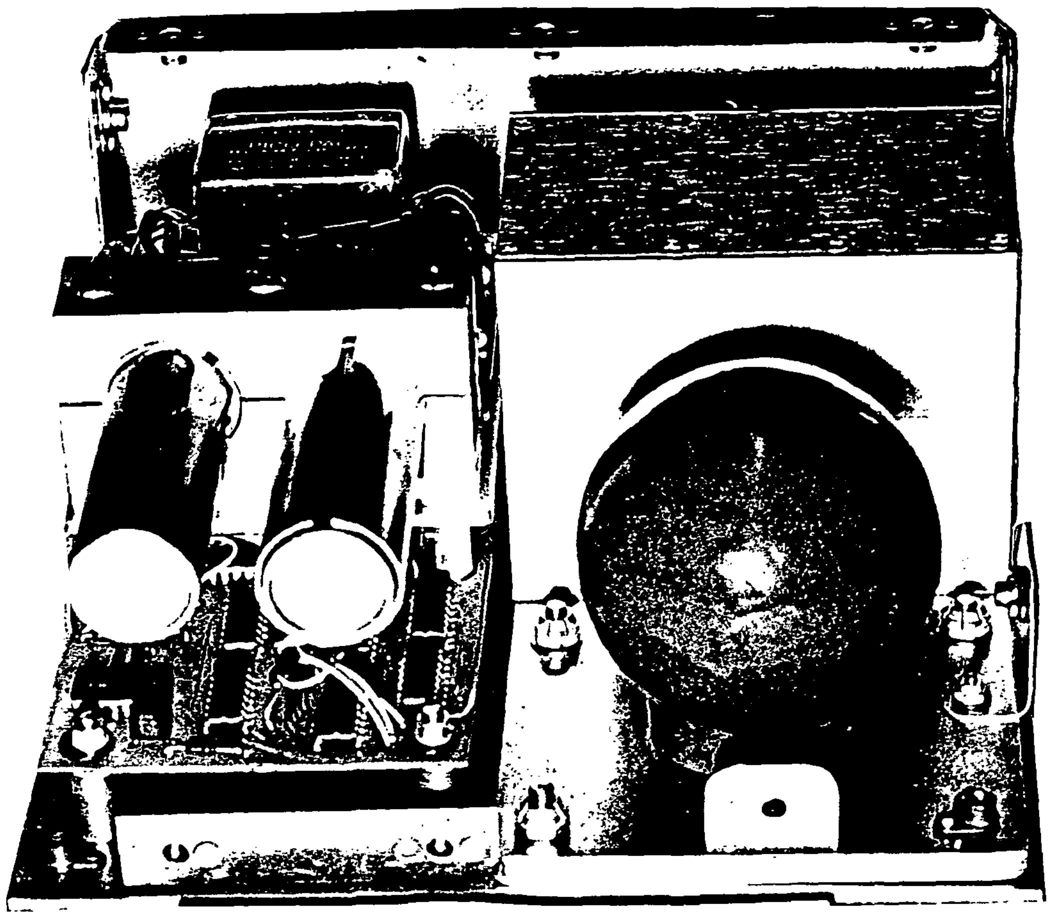
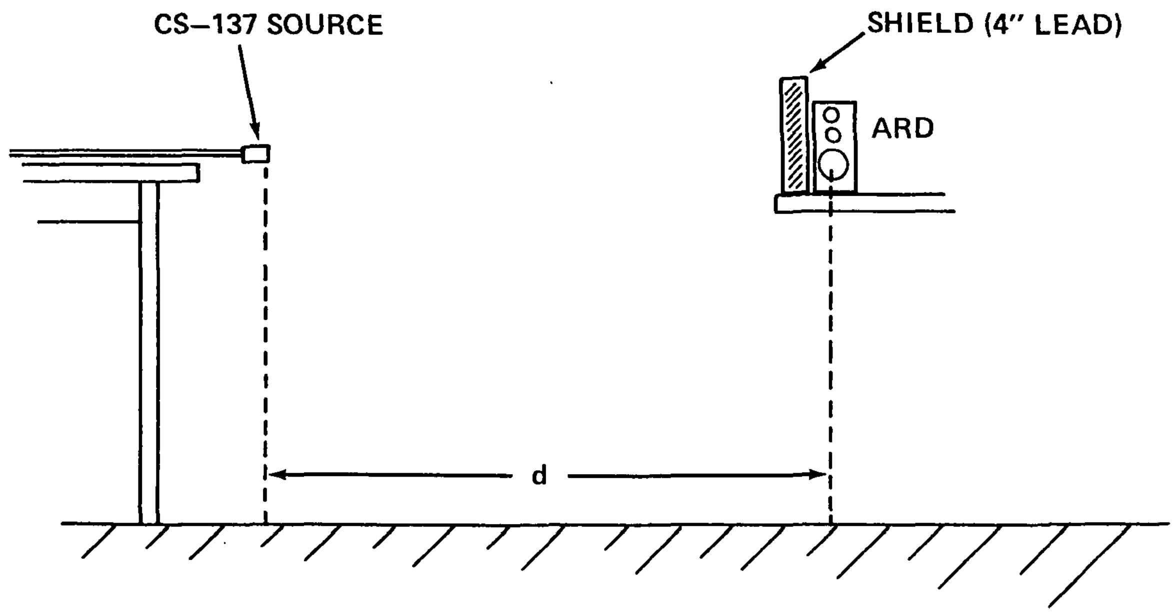


FIGURE 1. ACTIVE RADIATION DETECTOR
(PROTECTIVE COVER REMOVED)



ARD CALIBRATION
EXPERIMENTAL SETUP: SHADOW SHIELD METHOD

FIGURE 2.

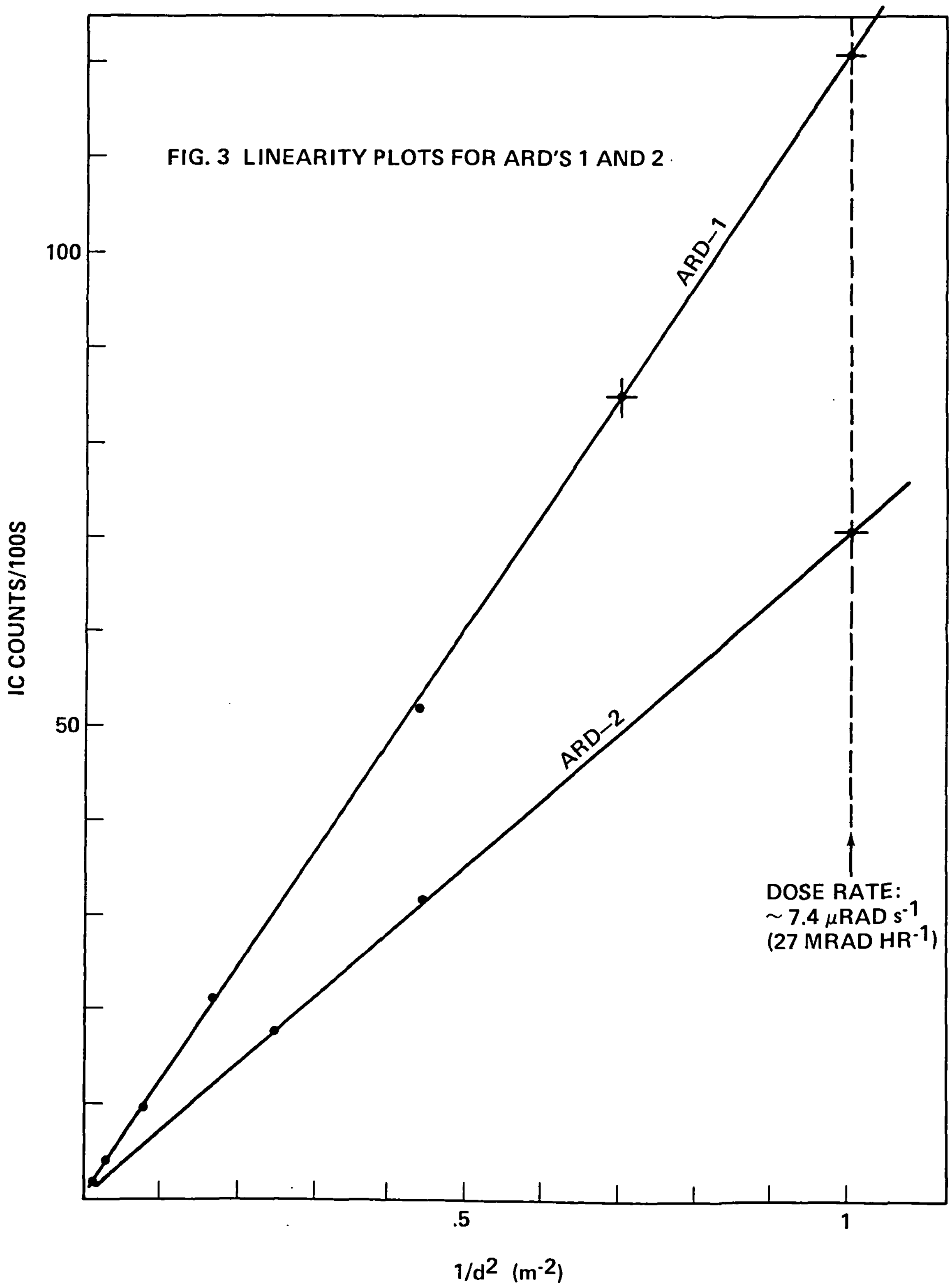


FIG. 3 LINEARITY PLOTS FOR ARD'S 1 AND 2
ARD–1
ARD–2
100
50
IC COUNTS/100S
.5
1
1/d2 (m-2)
DOSE RATE:
~ 7.4 μRAD s-1
(27 MRAD HR-1)

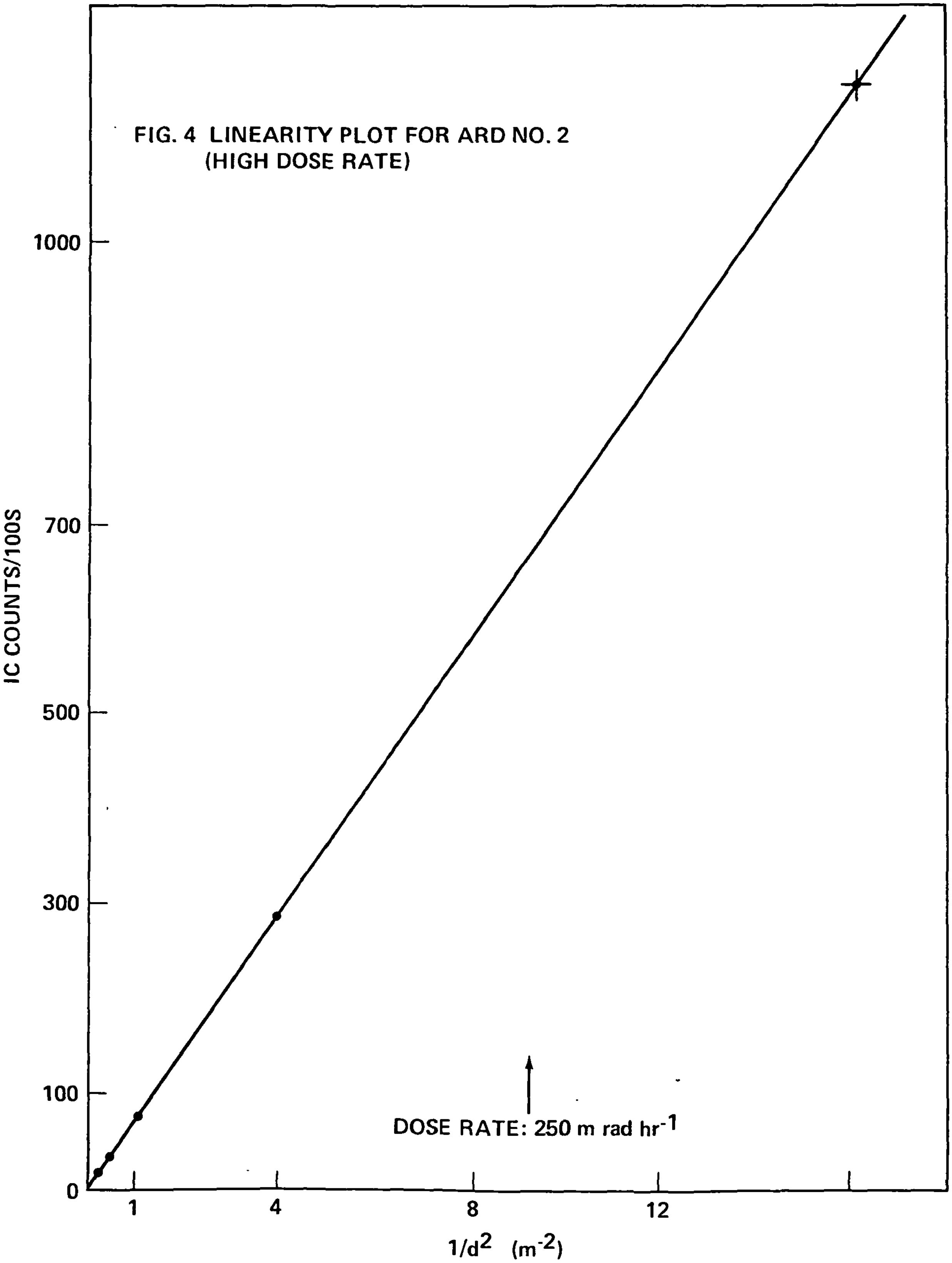


FIG. 4 LINEARITY PLOT FOR ARD NO. 2
(HIGH DOSE RATE)
IC COUNTS/100S
1000
700
500
300
100
0
1
4
8
12
1/d2 (m-2)
DOSE RATE: 250 m rad hr-1

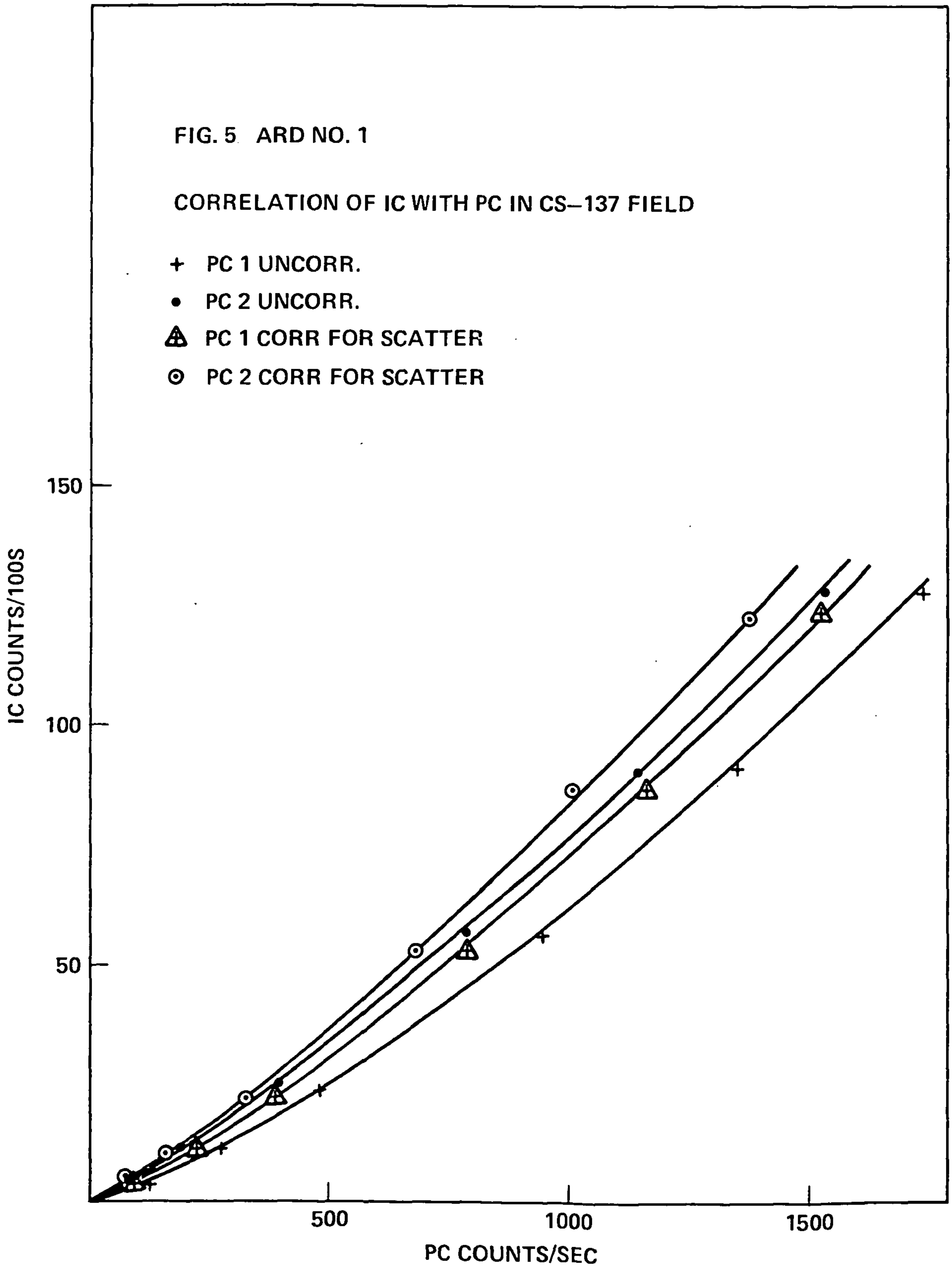


FIG. 5 ARD NO. 1
CORRELATION OF IC WITH PC IN CS–137 FIELD
+ PC 1 UNCORR.
• PC 2 UNCORR.
PC 1 CORR FOR SCATTER
PC 2 CORR FOR SCATTER
150
100
50
IC COUNTS/100S
500
1000
1500
PC COUNTS/SEC

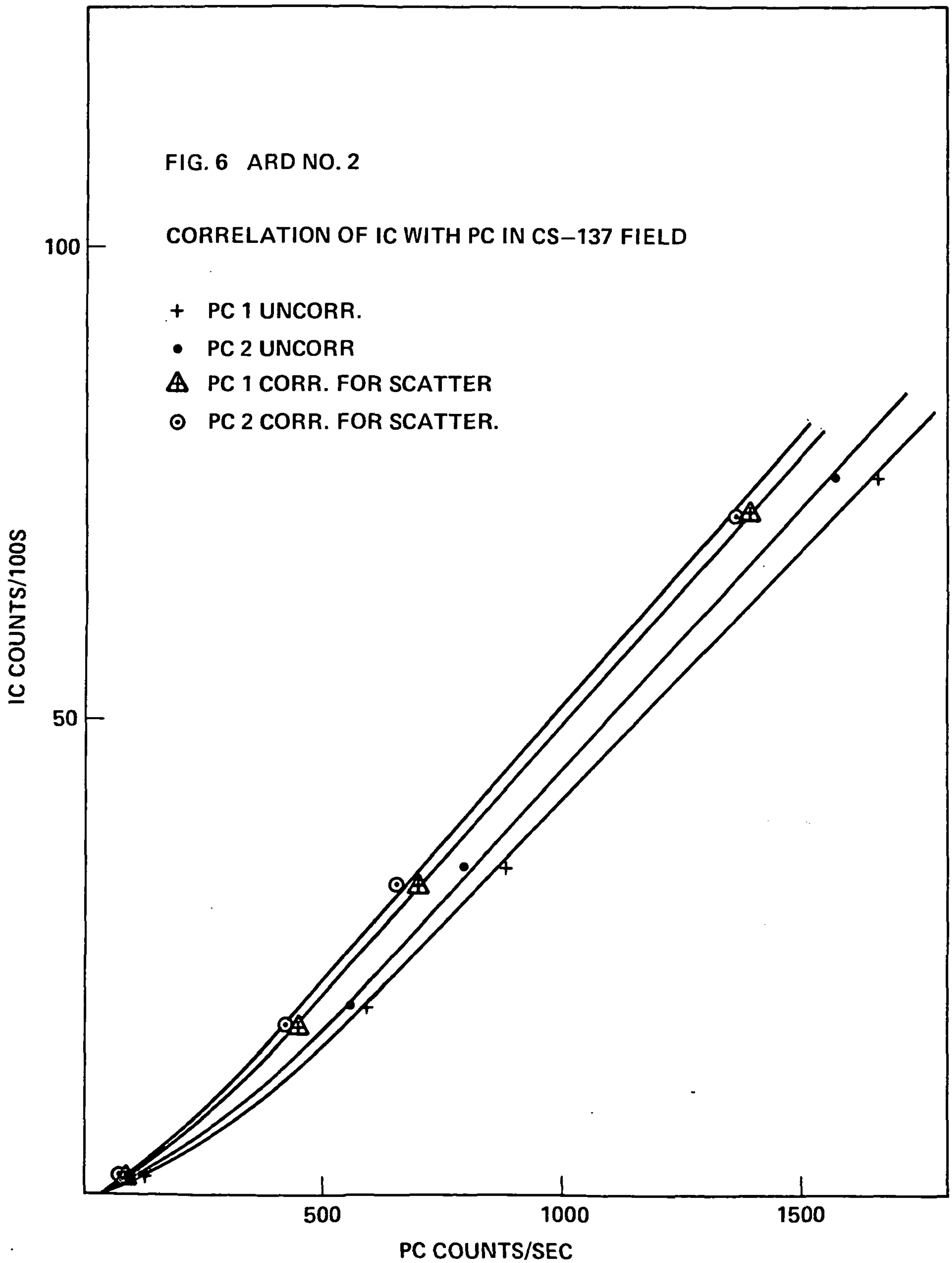


FIG. 6 ARD NO. 2
CORRELATION OF IC WITH PC IN CS–137 FIELD
+ PC 1 UNCORR.
• PC 2 UNCORR
PC 1 CORR. FOR SCATTER
PC 2 CORR. FOR SCATTER.
IC COUNTS/100S
100
50
500
1000
1500
PC COUNTS/SEC

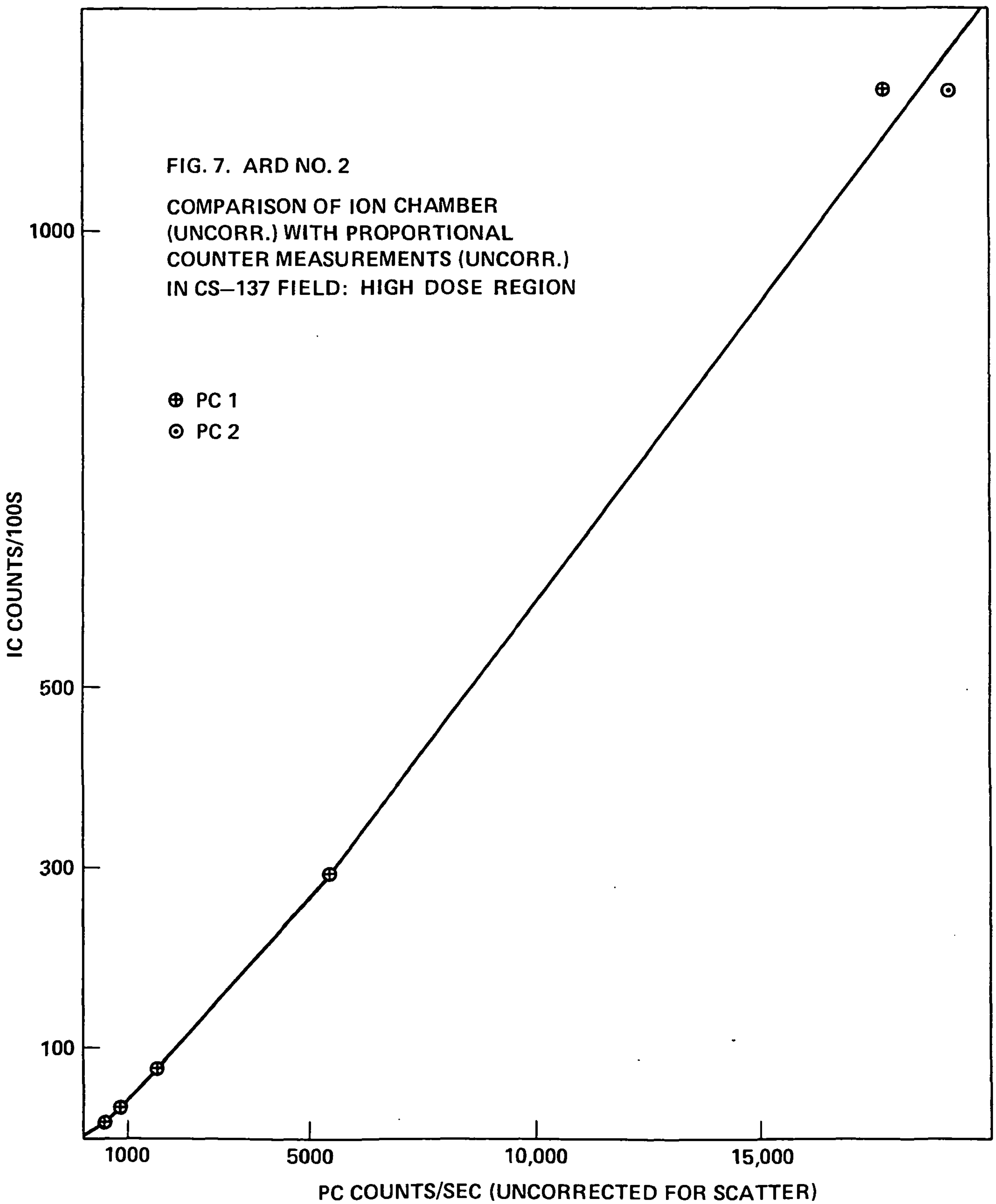
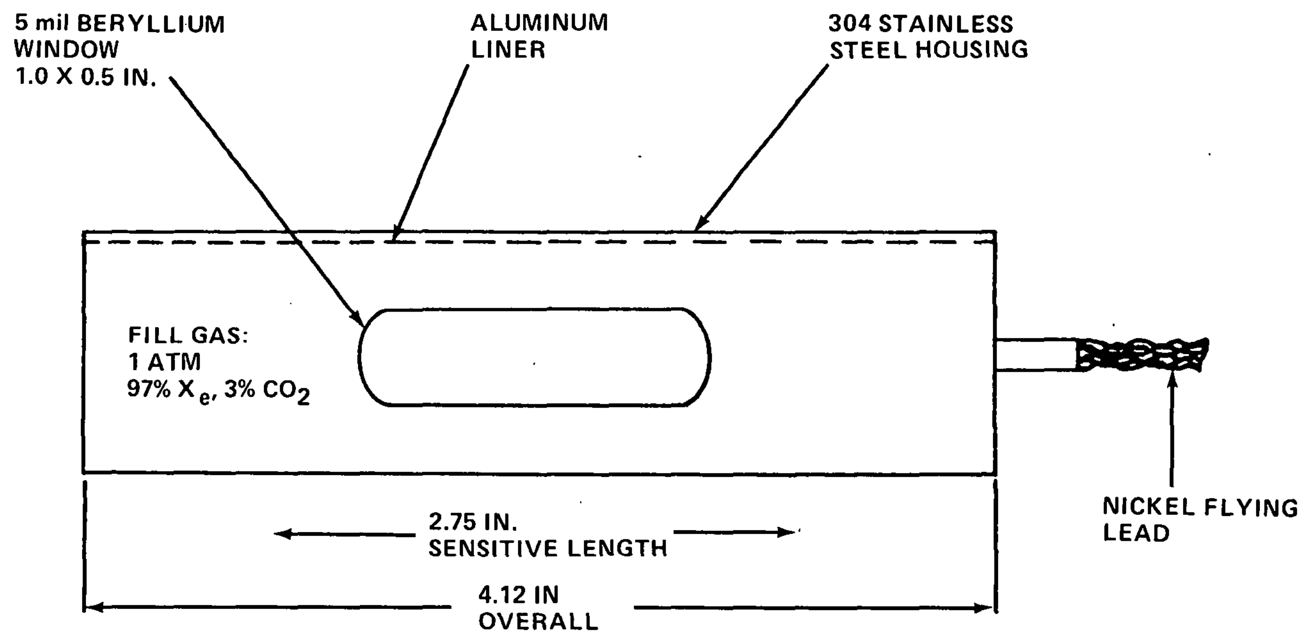


FIG. 7. ARD NO. 2
COMPARISON OF ION CHAMBER (UNCORR.) WITH PROPORTIONAL COUNTER MEASUREMENTS (UNCORR.) IN CS–137 FIELD: HIGH DOSE REGION
⊕ PC 1
⊙ PC 2
IC COUNTS/100S
1000
500
300
100
1000
5000
10,000
15,000
PC COUNTS/SEC (UNCORRECTED FOR SCATTER)



PROPORTIONAL COUNTER (PC) FOR ARD
(REUTER–STOKES RS–P3–0803–287)

FIGURE 8.

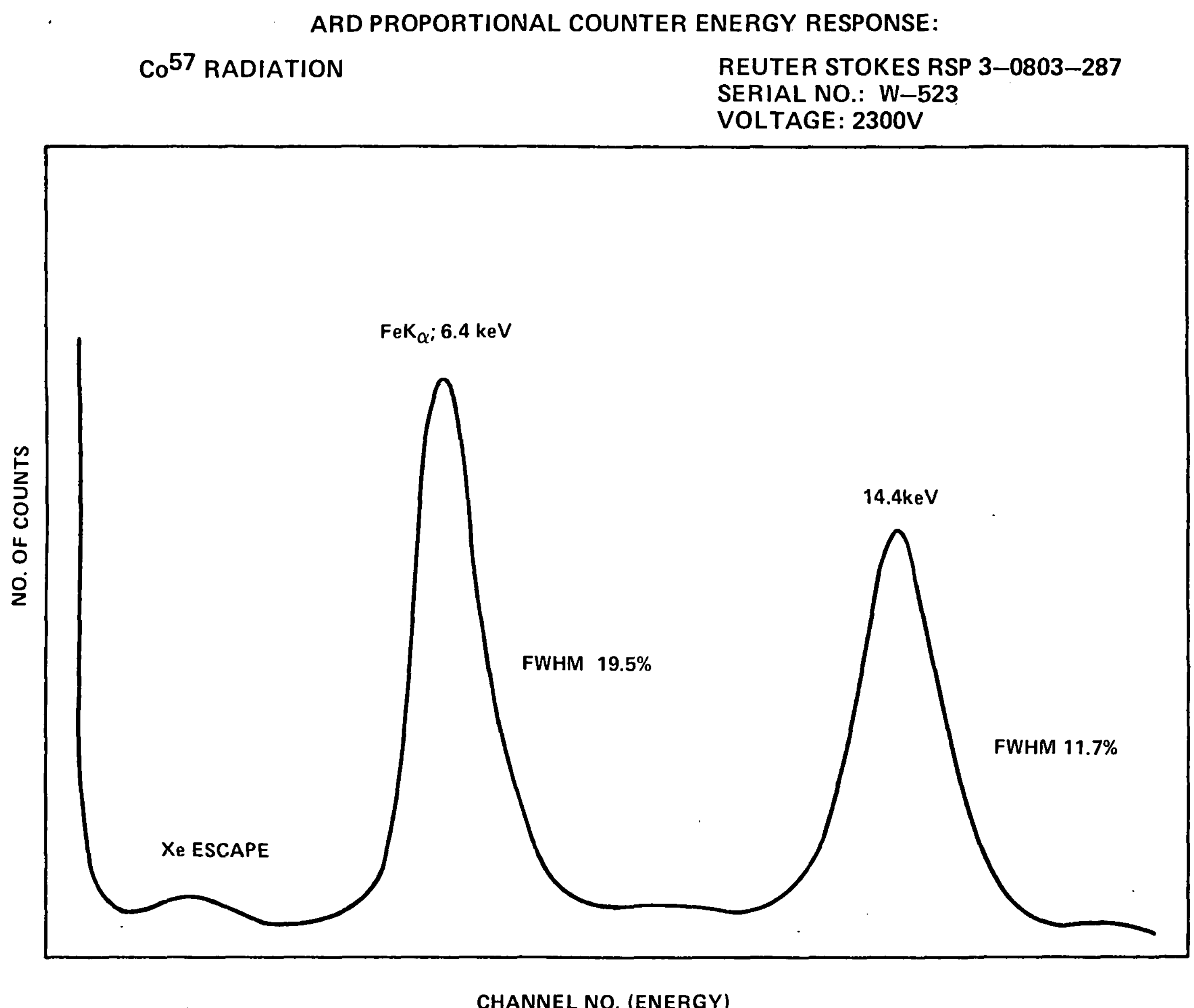

ARD PROPORTIONAL COUNTER ENERGY RESPONSE:
Co^{57} RADIATION
REUTER STOKES RSP 3–0803–287
SERIAL NO.: W–523
VOLTAGE: 2300V
NO. OF COUNTS
Xe ESCAPE
FeK_{α}; 6.4 keV
FWHM 19.5%
14.4keV
FWHM 11.7%
CHANNEL NO. (ENERGY)

FIGURE 9.